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POSSIBLE CAUSES
OF THE
DECLINE OF OIL WELLS
AND SUGGESTED METHODS OF PROLONGING YIELD

BY

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POSSIBLE CAUSES OF THE DECLINE OF OIL WELLS AND SUGGESTED METHODS OF PROLONGING YIELD.

By L. G. Huntley.

INTRODUCTION.

The purpose of the petroleum technology investigations that are being conducted by the Bureau of Mines is to aid in extending more efficient methods in the production, handling, refining, and marketing of petroleum and its products. This paper deals with one feature of greater efficiency in production, since the decline of individual oil wells is the immediate or direct factor in the general decline of production throughout all fields that have been discovered to date and will be in the decline of all future fields. The efficiency of the recovery of petroleum from its underground sources can be measured by the length of time during which economic production can be sustained in individual wells or groups of wells, the object being to leave in the sand when the well is finally abandoned the least possible percentage of the original petroleum content. The methods that by prolonging the life of wells are helpful in extracting the maximum amount of oil at minimum cost are briefly summarized on the following pages.

CAUSES OF DECLINING YIELD.

The reasons for the decline of oil wells may be grouped in two classes—those due to natural causes and those due to poor management. Since the early days of the petroleum industry improvements in methods of production have to a large extent been confined to lessening the cost of drilling wells and to reducing the cost of surface operations. Although well-known physical laws offer a possible solution for all underground problems, yet the amount of carefully gathered data is so scarce that general deductions must be cautiously made. Hence this paper discusses both phases of the cause of decline, describes some of the remedial measures now employed, and gives suggestions as to possible means of bettering present methods of operating.

In general, the yield of a well declines in one or both of two ways: (*a*) Suddenly, after the initial spurt due to local relief of pressure, or (*b*) with relative slowness after the production has become settled.

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SUDDEN DECLINE OF YIELD.

In most districts the wells begin with a relatively large initial production that is followed by a rather rapid decline to a stage during which the decrease is more gradual. The initial spurt, which in many cases represents the flowing period of a well's life, is due to a relief of the supersaturated condition of the sand. The sudden release of pressure results in a spurt of petroleum, usually in the form of an emulsion with spray, caused by the expansion of the contained gases, that lasts for a variable length of time. The duration of this period of high production depends on local conditions, such as the porosity and structure of the sand, the extent and development of the pool, the character of the oil, the rock pressure, the position of the well with reference to the center of production, to salt water, and to other conditions of less importance.

Carrl [a] likens the producing life of an oil well in the high-grade oil fields to drawing beer from a barrel, as follows:

> The barrel is placed in the cellar and a bar pump inserted—at first the liquid flows freely through the tube without using the pump, but presently the gas weakens and the pump is called into requisition, and finally the gas pressure in the barrel becomes so weak that a venthole must be made to admit atmospheric pressure before the barrel can be completely emptied even by a pump.

This comparison is a general one and disregards all except the main factors of oil production.

RELATIVELY SLOW DECLINE OF YIELD.

The extent and rapidity of the succeeding decline is governed by several factors, which may be classified as follows:

1. Formation of waxy sediments that obstruct the passage of oil from the sand.
2. Decline of gas pressure in the district; that is, decrease of expulsive force, due to the exhaustion of the lighter or gaseous hydrocarbons.
3. Decrease in quantity of oil draining by gravity down the dip into the area affected by a well.
4. Decrease of the oil supply within the drainage area of a well on account of near-by development or the original limits of the pool.
5. Flooding by nonencroaching salt water under low pressure.
6. Flooding of the productive formation by salt water under high pressure.
7. Flooding by fresh water from the surface or from an overlying water-bearing formation.
8. Drilling of neighboring wells.

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[a] Carrl, J. F., The geology of the oil regions of Warren, Venango, Clarion, and Butler Counties: Second Geol. Survey Pennsylvania, vol. III, 1880, p. 262.

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9. Poor management, such as improper casing, unwise rate and time of pumping, and failure to clean.

One of the most important of the factors enumerated is the formation of obstructive waxy sediments in the productive stratum and in the tubing of the well, owing to excessive refrigeration incident to the free expansion of large quantities of gaseous hydrocarbons associated with the crude oil in the rock. That in some fields an early decline and seeming exhaustion is premature and can be credited to this cause is evidenced by the fact that when new wells are drilled near older wells that have ceased to produce the new ones give every indication of unimpaired pressures and vitality. It was a common occurrence in the northern Pennsylvania oil fields to find that the second and third crop of wells in old pools produced large quantities of oil after the territory had been abandoned as exhausted.

Carrl speaks of the producing formation as being a "practically sealed reservoir" so far as an individual pool is concerned. As an example, he mentions the Cashup (Pa.) pool, which was discovered in 1871, three or four years after the Pithole pool—2 miles to the southwest—had been practically exhausted. When tapped, the Cashup pool showed all the conditions normal to new territory and an abundance of lively oil, which attested its energy and force in a well flowing over 1,000 barrels per day.

The history of these pools has been duplicated in many places in Butler and Clarion Counties, Pa. Further evidence that the shorter life of the more recent development in southwestern Pennsylvania and West Virginia is not due to the draining of the oil and gas from the northern fields is the fact that the newer fields show much greater pressures and volumes of gas than the old fields ever did, even when encountered in the same producing sands.[a] To account for these changed conditions one must therefore look to causes other than any underground connection.

Another factor in the rapid decline of wells following the initial spurt is the relief from the supersaturated condition of the sand, allowing the drag caused by the friction of the oil through the sand to make itself apparent. The gaseous hydrocarbons in the immediate vicinity of the well dissipate themselves in the initial flow, and the production therefore falls off, owing to a lessening of the expulsive force. In flowing wells this marks the beginning of the "stripping stage." The character and porosity of the sand will influence the duration and amount of the initial flow, which, if from a loose, porous sand, will be more violent and will affect a larger radius than if from a fine compact sand.

Under ideal producing conditions the decline of a well would depend on only three main factors: (*a*) The quantity of oil available; (*b*) the

[a] Carrl, J. F., op. cit.; White, I. C., West Virginia Geological Survey, vol. 1, 1904, p. 171.

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rock pressure; and (*c*) the character and porosity of the sand. Hence, all efforts should aim at a proper understanding of the various conditions that complicate these main factors, govern the productivity of a well, and abnormally hasten its abandonment. The rapid decline of many wells from large producers to small pumpers, while at the same time large producers are being completed in the same vicinity, is evidence that these abnormal factors are at work.

DECLINE DUE TO THE FORMATION OF WAXY SEDIMENT.

Petroleum in the so-called paraffin-oil fields consists of hydrocarbons of the paraffin series, which range from the heaviest oil to the lightest gas. The gaseous constituents of petroleum exist in what may be likened to a solution, much like the gas in a bottle of soda water, and as such expand and escape when the pressure is relieved by a well. The sudden expansion and volatilization of such light hydrocarbons has a refrigerating effect, like the expansion of ammonia gas in an ice machine, chilling the remainder of the liquid petroleum and causing the separation of the heaviest paraffin as an amorphous waxy sediment.

As an example of this process, a simple experiment described by Miles W. Quick, of Titusville, Pa., in an unpublished manuscript may be mentioned. A sample of light oil was cooled to a temperature of 25° F. until it was cloudy to the top. When the sample was warmed to between 60° and 70° F., the original temperature, the cloudiness did not disappear. After further heating, which caused all congealation to disappear, the sample was again cooled to 35° F., and the top half was decanted off and labeled "Sample 1." The part of the original sample remaining in the bottle was called sample 2. When sample 2 was warmed, its appearance was identical with that of sample 1, yet when sample 1 was cooled to a temperature of 35° F. no congealation took place, whereas at this temperature sample 2 was cloudy with amorphous paraffin.

Several interesting deductions may be made from the experiment. In the first place, although Carrl states that oil and gas appear to exist in the rock, not as distinct bodies, but as one substance—gaseous hydrocarbons being incorporated with the oil as gas with water in a bottle of soda water—yet the experiment described above shows that under certain circumstances "stratification" does take place. The free escape of the light hydrocarbon gases, as allowed at most wells, gradually changes the relative composition of the oil remaining in the rock, until the accompanying refrigerative effect of the gas expansion and vaporization is sufficient to lower the temperature of the oil in the immediate vicinity of the well by overcoming convection from the surrounding rock. This results in the formation of waxy paraffin sediments, which, combining with water and fine rock sediments, clog the pores of the sand and obstruct the passage of the oil into the well.

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This process accounts for the sudden failure of many wells, some situated in unexhausted territory. The drop of a few degrees near a certain critical temperature has more effect on the congealation of the oil in a well than a preceding 20-degree change in temperature. Hence, when the petroleum becomes relatively high in heavy paraffin constituents, or, conversely, low in its percentage of light hydrocarbons, which have been exhausted in the early stages of production, the wax will soon clog the outlets and production will end abruptly. To repeat, this result is brought about both by the free escape of well gases and by the stratifying of the oil, as indicated in the experiment described above.

DECLINE DUE TO THE EXHAUSTION OF THE GASEOUS HYDROCARBONS.

The decline of gas pressure in the pool through the exhaustion of the lighter hydrocarbons acts in a variety of ways to cause the decline of wells. In the first place the reduction of the specific gravity of the oil remaining in the rock indirectly affects the production, as described in the preceding paragraph. The practice of allowing the free escape of vapors instead of endeavoring to make each cubic foot of gas in expanding perform its quota of work in the expulsion of liquid petroleum, is a direct cause of the decline of flowing wells. It is almost as direct a factor in the decline of pumping wells as the intrastrata gas pressure is the means of keeping up the continuous movement of the fluid toward the well when the well is pumped.

As another indirect effect, may be mentioned the flooding of oil pools by water, owing to the injudicious rapidity with which the gas is drained from the pool. The rapid exhaustion of the gas in a certain part of the field may remove the only influence retarding the encroachment of water, which may, by a flanking movement, cut off a large section of the producing area. Or water may exist in the lower part of the oil sand, being held in check only by the rock pressure of the gas. If each cubic foot of gas were retained to perform its work of expelling petroleum, the pressure would help to retard the water for a considerable period, or until the maximum amount of oil had been recovered. The Hogshooter pool in Oklahoma is an example of a producing gas district that has been ruined by having its gas drained too rapidly. Wells were commonly drawn upon to their utmost capacity; hence, as no pressure restrained the water under high pressure in the lower part of the productive formation it flooded one well after another. Although Oklahoma has a law requiring that 50 per cent of the open-flow capacity must be retained in the well, little attempt was made to comply with this law. In some pools, such as the Hogshooter, it is

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believed that not over 15 per cent of a gas well's capacity should be turned into the pipe line at any time, the remainder being retained in the well to keep back the water.

DECREASE IN THE QUANTITY OF OIL DRAINING BY GRAVITATION INTO THE AREA INFLUENCED BY A WELL.

The effect of gravitation in many pools is usually overlooked. That gravitation tends to cause the accumulation of the remnant of oil in some pools is undoubted; and some instances of abandoned fields that have been rejuvenated and are again productive can no doubt be explained on this basis. In a fine-grained sand move-

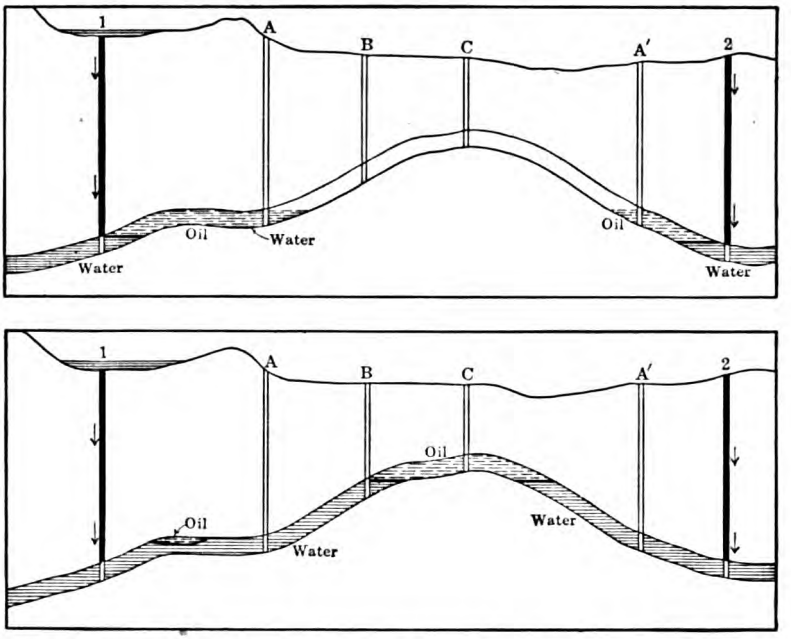

FIGURE 1.—Effects of flood water and arrangement of wells drilled to utilize flood-water pressure.

ment by gravity may be so slow as to make it of no consequence during the operation of an oil operator's lease. However, in a soft or very porous stratum of rather pronounced dip, or one that lies in such a manner as to form a decided catchment area for oil, the movement down the dip may in a comparatively short time replenish the oil drained off by wells. This factor should therefore be recognized. In fact, in some pools it may explain the total production of many small wells.

A coarse vesicular oil rock would be particularly favorable for this movement. In the Oil Springs pool in Ontario, advantage is taken of the annual advance of oil ahead of the fresh water influx from the spring freshets. As indicated in figure 1 the water in this

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locality obtains entrance to the oil rock through abandoned wells (as 1 and 2 of the figure) drilled from low points on the surface Certain "live" wells located at strategic points are pumped successively, resulting in a large recovery. The possibilities of such procedure are readily apparent.

Of especial interest in this connection are the possibilities of introducing water into wells located at the crest of the dip to aid in the gravitation of the oil, assuming that the oil is already concentrated in large enough quantities to make drilling pay. This movement down the dip to a catchment area would probably be accelerated by drilling wells at high points on the dip to admit atmospheric pressure behind the oil. This would appear a necessity, as under the assumption that the oil rock is an air and fluid tight reservoir a medium for replacing the oil would have to be furnished from an outside source. This theory disregards the factor of gas pressure, which in fields producing heavy asphaltic oils is negligible, and in many cases is entirely dissipated in the early history of some high-grade oil fields.

In fine-grained sandstone, such as the Clinton sand in central Ohio, capillarity may so retard the action of gravity that the latter may be neglected by the operator, especially in a region of low monoclinal dips such as exist in that part of Ohio. In certain of the older Pennsylvania and West Virginia fields, however, this force may be the explanation for the "coming back" of old districts, a phenomenon that caused pioneers in the oil industry to believe that oil was being formed continually in underground sources and that its exhaustion was impossible. In fact, speculation as to the possible "coming back" of many pools has led to the spending of thousands of dollars in comparatively recent years, when carefully collected information might have shown such expenditure to be useless. Again, assuming with Carrl that the oil rock is a "practically sealed reservoir," a modification of the theory of the action of gravitation in the recovery of oil may be necessary to account for wells that produce little or nothing until later wells are drilled higher up the dip, when the first wells show a marked improvement in production. The movement of the oil down the dip is then seemingly aided by atmospheric pressure from above. This theory also assumes an absence of original rock pressure or its previous exhaustion. An atmospheric pressure of 15 pounds per square inch in the wells first drilled is sufficient to keep back the oil until an equalizing pressure from behind is applied. If gas exists in the rock, its expansion will furnish this replacing medium.

The production of some wells improves after the drilling of neighboring wells, a result that may probably be explained on a basis similar to the above. In oil wells the atmospheric pressure, combined with the retarding capillarity of the sand, may be sufficient to

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prevent recovery. However, the contrary effect was observed in two wells in the pool at Vinton, La. The oil is of a heavy asphaltic base with no gas. The first well encountered a "pay" sand so soft that the rotary bit dropped through of its own weight. It began to produce oil and continued until a second well was drilled close by. This second well struck the same sand in the same condition, but it immediately collapsed or "packed" and thereafter neither well produced a gallon of oil. As the rest of the field was pumping oil from this sand, and as the oil in the sand was therefore under less than atmospheric pressure, the admission of air to the sand in the second well, combined with the draft in the direction of the pumping wells in older parts of the pool, may have been sufficient to drive the oil in that direction, the sand then collapsing, possibly from atmospheric pressure, as the drillers state that the well was not flooded.

The famous Triumph pool in Pennsylvania is a historic example of wells pumped at less than atmospheric pressure.[a] The gas pumps kept from 10 to 12 pounds vacuum on the sand at all times, thus relieving the pressure sufficiently to allow the recovery of the oil. In such pools as this, if conditions permit, air holes drilled at strategic points and left open would undoubtedly result in the flow of oil toward the pumping wells, without the added expense of gas pumps. In other districts where recovery is small, a like procedure would be a profitable means of more rapid recovery, if proper care were exercised. It is, however, true that in many wells air reaches the oil sand between the bottom of the casing and the end of the tubing, and that by connecting a vacuum pump to the casing the flow of oil is increased.

In some regions where the dip of the rocks is steep, as on pronounced anticlines or monoclines, the action of gravitation on the flow of wells is noticeable, and those wells located up the dip will tend to drain the oil from those lower down. Rival producers, in locating their wells, take advantage of this action. The best practice is, of course, to space wells closer across the dip than in the line of dip. Figure 2 illustrates the lines of flow into two interfering wells in a region where the dip, and hence the gravitational movement of the oil, is in a general direction.

Figure 3 also illustrates this condition. As part of the oil is drained from the pool by wells, the remaining part tends to move down the slope of the sand, lowering its upper level so that wells located up the dip (as well A in the figure) cease producing, some of them probably developing a small gas production. As this action proceeds, a well farther down the dip (as well B in the figure)will begin to fail, until a well located as at C will be the only producer and hence the longest-lived well in the pool.

[a] Carll, J. F., The geology of the oil regions of Warren, Venango, Clarion, and Butler Counties: Second Geol. Survey Pennsylvania, vol. III, 1880, p. 260.

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DECREASE OF OIL SUPPLY ON ACCOUNT OF NEAR-BY DEVELOPMENT.

In those pools in which the decline has been normal, with a maximum recovery of the oil, decline in production will depend only on the exhaustion of the gas pressure and the decrease of the available underground supply. Advantage is sometimes taken of natural forces that tend to conserve the expulsive energies of the petroleum in the rock, thus preventing the formation of excessive obstructive sediments and eliminating water problems until later in the life of the well. The character and porosity of the oil rock affect the extent of the drainage, the most favorable material for rapid drainage being a sandstone that is coarse and porous, though not loose enough to allow the setting up of sharply defined drainage channels by the flow of oil and water through the sand. On the other hand, more sudden gas expansion takes place in such a sand than in one of a close texture, and if the oil becomes chilled wax will form unless care is exercised.

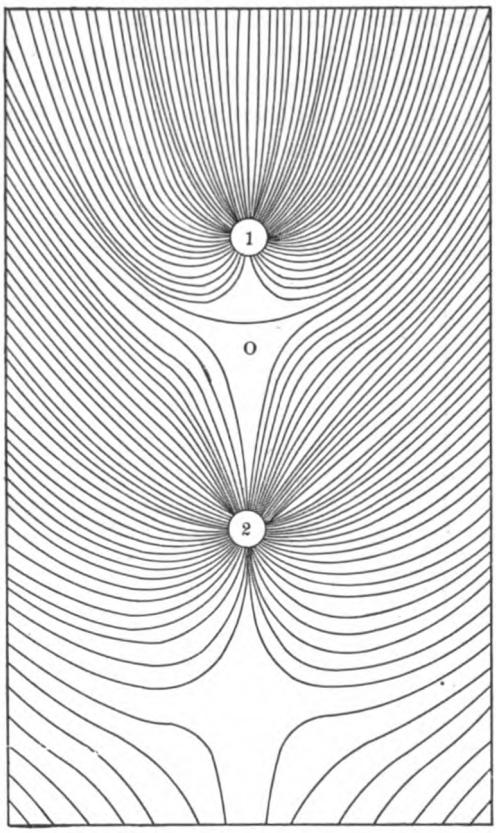

FIGURE 2.—Lines of flow into two interfering wells.

The decrease under consideration occurred at the Petrolea, Oil Springs, and Bothwell pools in Ontario, the wells in those pools exhausting from the outward edges of the productive area inward. The famous Glenn pool of Oklahoma is another example, the oil sand being coarse, porous, and uniform in texture, there being no water problem and no excessive waxing of the sand face or the pumping rods. Pumping is regular and consistent, and the wells as a rule are uniformly spaced. As a result the decline is normal and gradual, the fluctuations in the production of a group of wells occurring only at times of cleaning or as a result of unfavorable pipe-line conditions. Curves 2 and 4 of figure 4 represent nearly ideal production curves of groups of wells in the Glenn pool, Oklahoma.

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There have been oil wells and gas wells that increased their production for a time after a neighboring well had been completed. In the Mansfield district south of Shreveport, La., both the pressure and the volume of some of the pioneer gas wells increased greatly for the first few months. The increased production in such cases is probably due to the cleaning out of seepage and drainage channels in the rock as a well is drawn upon. Although one well had an initial pressure of 60 pounds, which increased in four months to more than 250 pounds closed pressure, yet if the well had been closed for a sufficient length of time to allow the full pressure to accumulate in the casing the initial pressure would probably have equaled that recorded later. Such wells are usually evidence that the drilling has been done near the edge of an oil or gas pool and not in the best place. Carrl [a] states that as a rule the first wells drilled

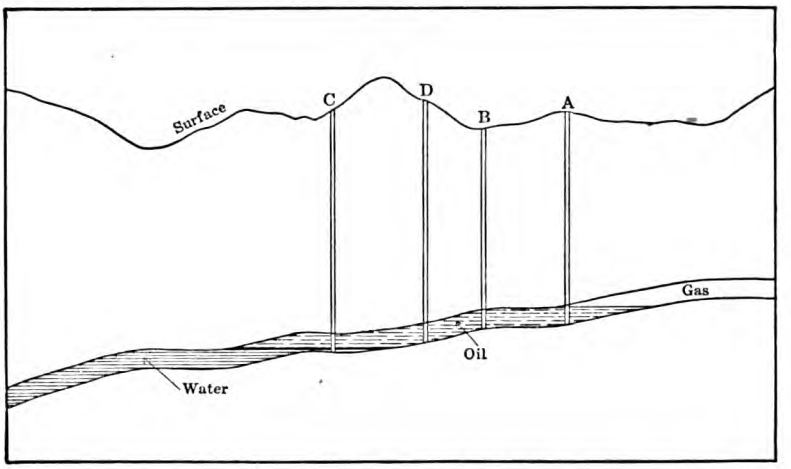

FIGURE 3.—Effect of movement of oil and exhaustion of oil sand on yield of wells.

in a new pool have greater productiveness than those drilled later, but that if the first wells are drilled at the edge of a pool in poor rock, wells subsequently drilled at the center of production will drain the pioneer wells, whose high initial yield is largely due to the original rock pressure being sufficient to counterbalance the effect of the tight, close sand.

As illustrative of the conditions mentioned, Carrl [b] cites the National well No. 1, drilled in February, 1866, and situated a few rods from the National No. 2, in the Pleasantville district.

It was very near the edge of a large and well-stored pool and passed through rather an inferior oil rock, as compared with that afterwards found on the axis of the belt; still it had a sufficiently free connection with the supplying reservoir to furnish a

[a] Carrl, J. F., The geology of the oil regions of Warren, Venango, Clarion, and Butler Counties: Second Geol. Survey Pennsylvania, vol. III, 1880, p. 259.

[b] Carrl, J. F., op. cit., pp. 258, 259.

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delivery of about 85 barrels per day, and it maintained its production with wonderful constancy for two years, having declined only to about 60 barrels in that time. In the summer of 1868 wells were drilled in the main pool from which it had been deriv-

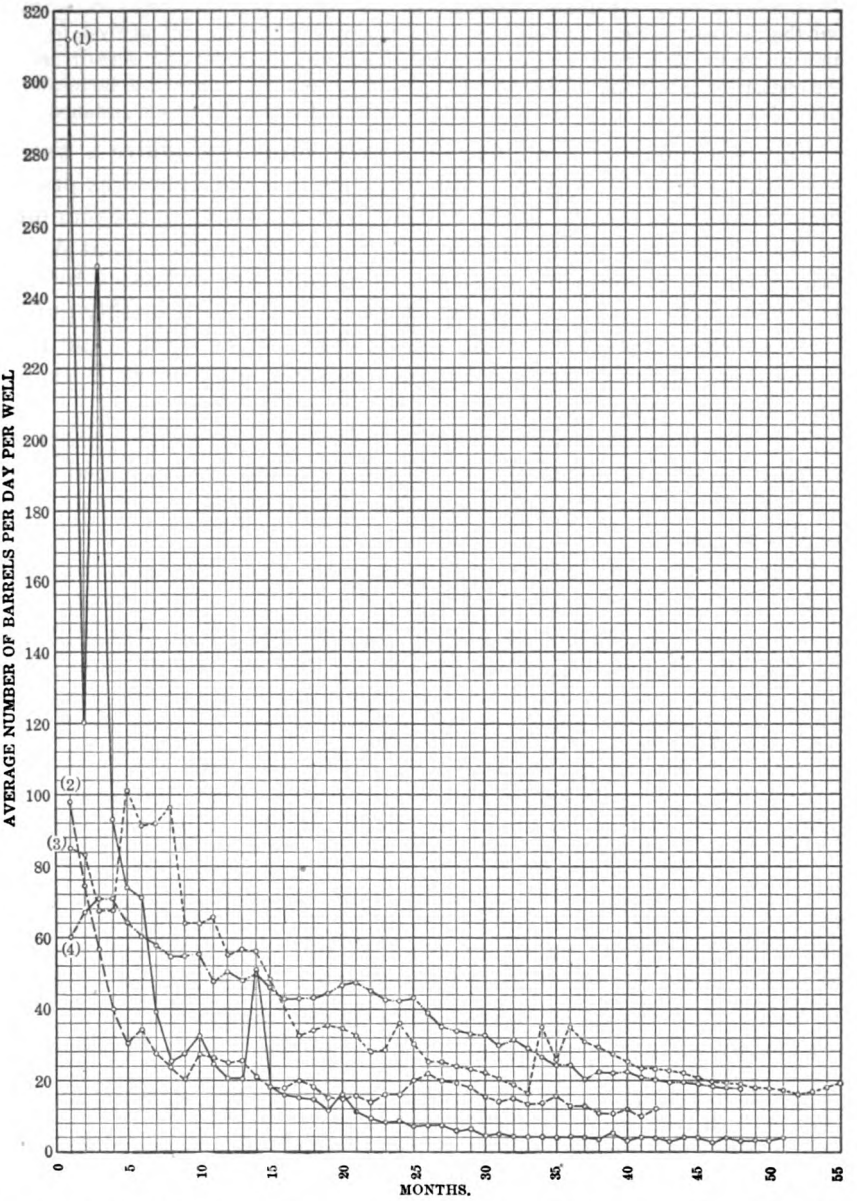

FIGURE 4.—Typical production curves of wells in the Mid-Continent oil field. Curves represent production under leases as follows: 1, Muskogee district, Oklahoma; 2, Bartlesville district, Oklahoma; 3 and 4, Glenn pool, Oklahoma.

ing its supply. Some of these wells produced as much as 150 barrels per day. The effect upon the National was immediately apparent. Its production dropped off rapidly and dwindled down to 10 barrels or less per day.

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The Harmonial well No. 1 was on the northern edge of the Pleasantville belt. The main body of oil and the best sand rock, as was afterwards demonstrated, lay to the south. It started with a small yield and at the end of a fortnight was pumping about 30 barrels per day. Gradually increasing its production, as if enlarging and cleaning out the passages leading into the supplying reservoir, it finally commenced to flow and ran up to 125 barrels, where it remained until wells of larger flow were drilled in the center of the belt and relieved the gas pressure, when pumping had to be resumed. After this it soon fell down to an unremunerative production and was abandoned.

Figure 3 shows oil occurring on a monoclinal dip, above a water-saturated zone in the sand. The water level is considered as practically nonencroaching. As the oil body shrinks, owing to the pumping of the wells, the upper level will drop, and wells situated as at A will fail, possibly developing a little gas production, followed by the failure of wells, as at B. Meanwhile a well, as at C, is probably pumping somewhat more water with the oil than are the others, and may perhaps be entirely flooded, leaving wells situated as at D as the longest-lived wells in the field.

The position of an oil property with respect to producing territory should be studied carefully, for the knowledge to be gained from such study will be of much assistance in arriving at a fair valuation of the property.

Practically, so far as the oil man is concerned, an oil-bearing rock before being drilled may be considered as a "sealed reservoir," and as oil and gas are recovered from it their places will always be taken by some other medium, as nature tends to restore equilibrium. This replacement may be made by the expansion of gas from the same formation, or by air admitted through wells; but in most fields this replacing agent is salt water from the same stratum, fresh water from the surface seeping through old wells, or water entering from an overlying formation through badly packed or carelessly plugged wells.

Carrl [a] says in this connection:

> The flooding of an oil district is generally viewed as a great calamity, yet it may be questioned whether a larger amount of oil can not be drawn from the rocks in that way than in any other; for it is certain that all the oil can not be drawn from the reservoir without the admission of something to take its place.

This something may be gas or water from the surrounding rocks or air entering through older wells.

DECREASE DUE TO ENCROACHMENT OF SALT WATER UNDER HIGH PRESSURE.

Encroachment of salt water may result from what may be called oil and gas displacement. If the salt water lies in the lower part of a porous formation overlain by the oil, both being under pressure of the gas above, and if a well taps both the oil and the water the gas pressure above the pool, acting downward on the oil and the water,

[a] Carrl, J. F., op. cit., p. 263.

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causes them to rush to the well outlet. If the water is in greater quantity than the oil, it will often in a short time flood the well entirely, the oil and the gas forcing their way downward into the formation to take the place of the expelled water. The oil is thus lost beyond recovery, and the well continues to produce nothing but large volumes of water. In pools like the Bird Creek pool and certain other northern Oklahoma pools, the initial wells were abandoned in some parts of the district, whereas, after the gas pressure had been diminished as a result of drilling other wells, it would have been possible to have pumped oil from the top of the sand without being troubled by water, because the water would then have been under less pressure. These early wells, which were allowed to blow wide open,[a] also caused the waste of enormous quantities of gas.

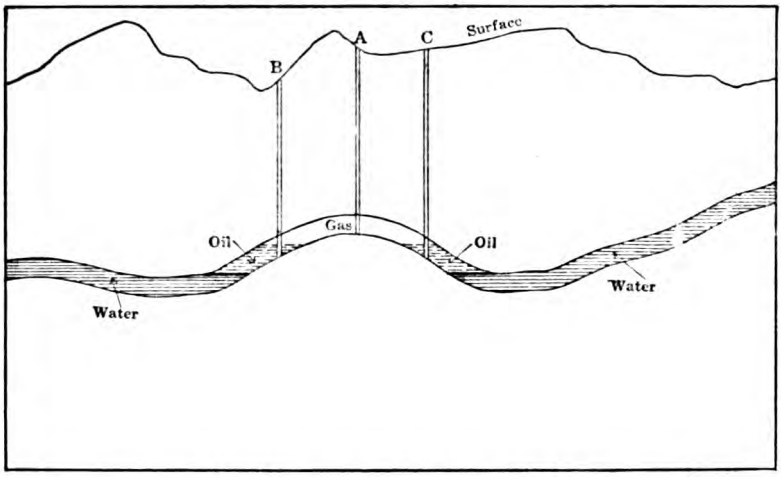

FIGURE 5.—How true encroachment of water occurs.

True encroachment to restore equilibrium may occur in a field where there is a strong hydrostatic head counterbalanced by the gas pressure existing in an oil pool or by a corresponding head of oil, as shown in figure 5. As the gas is drained through well A the water advances until wells B and C are flooded, and the pool fails from its outer edges inward until possibly well A produces a little oil along with some water, and in its turn is finally flooded.

By studying the direction of flow of encroaching water, certain wells can sometimes be reserved to be pumped for water alone, thus protecting the others of the group or pool from encroachment. Where a few large operators control production in a certain pool, cooperation in the study of such conditions and concerted action may result in a larger recovery of the oil in the pool than would be had by any other

[a] Arnold, Ralph, and Clapp, F. G., Wastes in the production and utilization of natural gas and means for their prevention: Technical Paper 38, Bureau of Mines, 1913, pp. 7–11.

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means. When many small operators are drawing from a pool, water encroachment is seldom made an ally instead of an enemy.

As a result of the encroachment of water part of the oil is crowded into the roof of the porous formation, and part advances ahead of the water, changing the relative status of the remaining wells with regard to the rest of the pool, and perhaps materially changing the shape and position of the remainder of the pool. The oil crowded

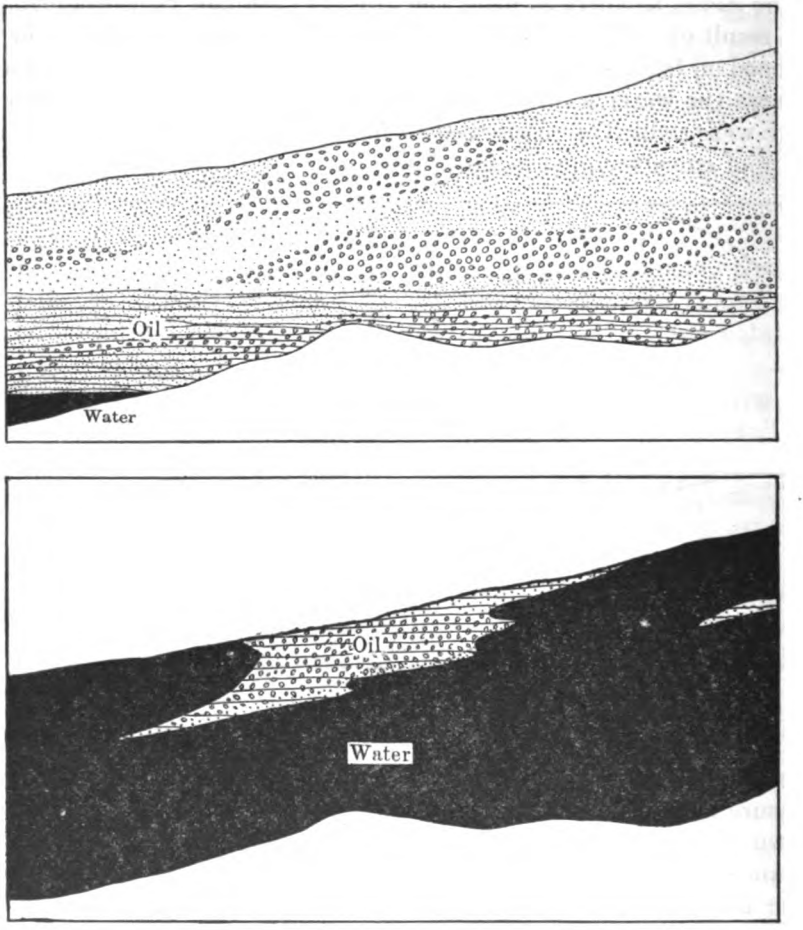

FIGURE 6.—Effect of water encroachment.

into the roof of the formation or caught in "crowns" or irregularities causes some water wells to continue to produce a little oil with the water, even though all the surrounding wells produce only water. This condition is illustrated in figure 6, which shows a pocket of oil retained by a porous lens in the sand after the encroachment of water.

Salt-water encroachment may also occur where the oil acts as the only force to restrain the encroachment. As wells are pumped

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drainage channels are set up in the sand, and water begins to follow the oil as the oil seeps toward the wells until only water wells exist. This form of encroachment is really a modification of the second case mentioned above, but can be more easily utilized to aid in draining a pool effectively.

Again, considering the oil sand as a "practically sealed reservoir," obviously something must be introduced to take the place of the oil that is being pumped out. A body of water under moderate pressure behind the oil will probably aid in moving the oil toward the wells as they are pumped and will result in the least possible amount of oil being left behind in the formation when the pool is finally abandoned.

DECREASE DUE TO FLOODING BY NONENCROACHING SALT WATER.

The occurrence of water in the lower part of the same porous formation in which the oil is encountered is frequent in pools where the rocks lie almost level. Where such a condition exists, care is usually exercised to stop drilling just short of the water. However, an uneven formation may make it impossible to judge with certainty when to stop drilling. Possibly cleaning or shooting a well may cause it to break through into the water below, or an influx of fresh water from the surface or from an overlying formation may raise the water level above that originally existing in the oil sand. In such cases oil and water are pumped together and in many cases the total amount of water decreases in the course of time. However, certain classes of mineral water tend to "cut" the oil and cause the formation of obstructive waxes. It is believed that in some pools pumping the water with the oil is an aid to the oil recovery, the water tending to "flow" the oil toward the well.

In Oklahoma the high gas pressure in the early days of some pools has blown out such large quantities of water with the gas that many wells have had to be abandoned. When the pressure in such wells has decreased they may be pumped to advantage and may produce oil in large quantities, or by keeping the pressure of the gas as a restraining agent by using only a small percentage of the capacity of the well the water may be kept back and oil only recovered.

DECREASE DUE TO FLOODING BY FRESH WATER.

Owing to defective packers, to lack of care in plugging abandoned wells, and to accidents in drilling and casing, water is admitted to many oil-bearing formations from the surface or from an overlying water-bearing stratum. Depending upon conditions, this admission of water may have any one of several results.

If the volume of water is small, such as that seeping around a defective packer, or that due to temporary flooding before the packing

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is inserted, it may aid in the recovery of the oil by furnishing the medium necessary to take the place of the oil pumped out, thereby increasing the production of a well or group of wells.

If the quantity of water is large and the thickness of the porous formation is small, the water may force the oil back so far that it can not be recovered from the well affected. The inflow of water may, however, benefit other wells in the vicinity, helping the movement of the oil in other directions, and, the field being considered as a whole, may replace the oil pumped out and aid in its recovery. The pressure exerted by the column of water in a deep well is great, especially if the volume of water entering the well is sufficient to keep the column constant.

The flooding of fresh water no doubt accounts for some phenomenal production in fields where the recovery of petroleum from a sand rock has been relatively much higher than in other districts producing oil from a formation of equal thickness and porosity.

Attempts have been made to flood an oil-bearing formation so as to concentrate the oil in the formation and to effect a maximum recovery of the oil by water replacement. The practice is denounced by old operators in the Bradford (Pa.) field, and these efforts have met with indifferent success, not on account of fault in theory, but on account of insufficient data bearing upon underground conditions, varying porosities, etc., making intelligent prediction as to the movement of the oil an uncertainty. Clashing interests usually prevent such attempts on a large scale, wells belonging to rival operators being perhaps the first flooded although they may not be located so closely as other wells.

When water is admitted in large quantities it tends to flow out in various directions, the greatest flow following the line of least resistance. Owing to the differences in the resistance offered by sands of differing porosities and to varying amounts of gas in the rock, this movement of the water (and oil) in regions of low monoclinal dip—say, 15 to 20 feet to the mile—will extend up the dip as well as down. The movement will be particularly strong in the direction of very porous lenses and toward pumping wells, regardless of the effect of gravitation, the suction created by the pumping wells being sufficient to overcome the relatively slight tendency of the fluid to flow downward. This effect sometimes causes wells situated above the point of flooding to be affected ahead of the water wave and abandoned before those down the dip are affected. As an additional result the water wave, aided by irregularities in the structure and shape of the pool, will sometimes surround bodies of oil that were originally a part of the pool. Two or three such isolated pools are mentioned by Carll as having been discovered on the outskirts of the Pithole oil pool after the central part had been flooded.

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Again, lenticular pebble beds or lenses of unusually porous sand may form pockets in the upper part of an oil sand and may catch quantities of oil, which are retained as the main body of oil advances ahead of the water wave (fig. 6). These pockets furnish the oil in many wells that are entirely surrounded by flooded territory yet continue to produce a little oil along with large quantities of water.

The entering water may shift the whole body of oil from its original position, the extent of such shifting depending on the dip and shape of the pool and its underground structure. The Oil Springs pool in Lambton County, Ontario, is an example. When the pool was first developed it produced from a shallow "pay," an open vesicular stratum in the Corniferous limestone. The wells were all dug and were cased with Scotch casing of large diameter. At the time of the Fenian raid, the field was temporarily abandoned. When operations were later resumed it was found that the lower part of the casing in a great number of the wells had been corroded away, the wells had caved, and great quantities of fresh water from swamps on the surface had flooded the oil-bearing formation. Deeper drilling developed the present "pay" stratum at a lower depth, and the old wells were abandoned, as they could not, of course, be plugged.

In recent years wells drilled through this shallow stratum showed that the water had decreased, and one well struck oil. Other wells were drilled, and an attempt was again made to pump off the water.

These operations developed the fact that after the spring rains or any large freshet, quantities of fresh water seeping into this porous formation caused the water level to advance up the sides of the anticline upon which the pool is situated, carrying before it a considerable body of oil. By pumping certain wells, located at strategic points, in progressive rotation as the water and oil advanced or receded, considerable oil was recovered.

It was noticed that more oil was recovered upon the recession of the water than upon its advance. As the water advanced a part of the oil was probably caught and retained in the porous irregularities on the roof of the stratum. As the water receded these were again taken up by the main body of oil, increasing its quantity. This supposition is supported by the fact that a few wells would continue to produce a little oil with the water after the surrounding wells had all been flooded by the advancing water. This theory is illustrated in figure 1. 1 and 2 represent wells through which flooding takes place, whereas A, A′, B, and C represent wells pumped successively for oil as the water changes the relative position of the oil body.

One well is reported to have yielded 1,300 barrels of oil in three days before failing. As these shallow wells must be worked at great speed to effect a maximum recovery before being again flooded, pumps of large diameter and quick stroke are used.

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Owing to the unusual conditions and to the open vesicular nature of the oil-bearing stratum, the effects of flooding could be observed to good advantage in the Oil Springs pool. In most pools the "sand" is less porous, seepage and movement of the water and oil are slower, and local conditions complicate the problem.

The main factors affecting the flooding of an oil-bearing formation may be summarized as follows (adapted from Carrl)[a]:

(*a*) Time of flooding—whether early in the process of operations, while yet a large percentage of oil (and gas) remains unexhausted, or at a later period after the supply has suffered from long-continued depletion.

(*b*) Composition of the formation—whether regular and homogeneous throughout or composed of fine sand interbedded with irregular layers of gravel, in places lying near the top and in places near the bottom.

(*c*) Position of the pool—whether flat, as on a structural terrace, upon a monoclinal slope, upon the crest of an anticline, or at the bottom of a syncline.

(*d*) Shape of the area being flooded.

(*e*) Position of the point at which water is admitted in reference to the situation of surrounding wells still pumping oil.

(*f*) Height of the column of water obtaining admittance.

(*g*) Duration of the water supply. It will readily be seen that a temporary flooding in comparatively fresh territory, as from the drilling of new wells without casing and from the overhauling of old ones having the seed bag attached to the tubing in the primitive way, must necessarily be a different affair from a flooding caused by a permanent deluge through unplugged and abandoned wells in nearly exhausted territory.

> In the former case the flood may be checked before much water has accumulated in the rock, and then the oil flow can be reclaimed after a few days of persistent pumping; and in the latter the recovery of oil is very uncertain, because, for its long-continued extraction a greater capacity has been given to the rocks for storing water, and this being supplied from scattered and obscure sources there is little probability that it can be shut off, although the most thorough and systematic attempts be made to check it.[b]

In this connection may be mentioned the danger of drilling wells off shore along large bodies of water, as has been done in the Selkirk gas field in Ontario, along the California coast, and in the Tumbez oil field in Peru. An unlimited quantity of water, once admitted, will result in the flooding of an entire district.

On the other hand, the continuous entrance of relatively small quantities of water through leaky seed-bag packers in the early days

[a] Carrl, J. F., The geology of the oil regions of Warren, Venango, Clarion, and Butler Counties, Second Geol. Survey Pennsylvania, vol. III, 1880, p. 265.

[b] Carrl, J. F., op. cit., p. 266.

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of the Pennsylvania oil fields may have furnished the means necessary to prevent the chilling of the oil that was expelled through the free escape of large quantities of gas. The water so entering may have accounted for the continued productiveness of some wells, preventing the chilling of the oil and the formation of waxy sediments, and have been one of the factors in some of the phenomenal productions of that period.

Although in drilling wells by the old wet method [a] the heavy column of water may have prevented the early discovery of some oil-bearing strata, nevertheless the gas was conserved until utilized in the expulsion of oil. Some modern wells drilled by the dry method, all water being cased off while drilling is under way, encoun ter, especially in the Oklahoma fields, a strong flow of gas, which is blown off before the expulsion of oil commences. Were these wells drilled "wet" there is no doubt that in some cases this premature blowing of gas would be avoided, the oil would commence to flow immediately upon pumping out the water, and the rock pressure of the pool would be conserved for the continued expulsion of oil, thus increasing the ultimate production of the district. This great waste of natural gas is one of the extravagant practices and one to which little attention has been paid until now when the fields are on the point of exhaustion.

DECLINE DUE TO THE DRILLING OF NEIGHBORING WELLS.

In an oil pool situated in a region where the formations have a pronounced dip it will usually be found the best practice to space wells closer across the dip than down the dip. Figures 2, 7, and 8, from Slichter's [a] discussion of the mutual interference of artesian wells, show a number of ways in which oil and water are diverted by wells, either flowing or pumping. Figure 7 shows the lines of flow into a well in a region where the fluid has a constant motion in a general direction. If a second well were drilled in the neutral zone O, its production would be considerably smaller than that of well 1. This figure, in connection with figure 2, will indicate the advisability of spacing wells closer across the line of dip or flow than down the dip. In the West Virginia fields, and in a few Oklahoma fields, where operators control large blocks of territory, wells are being spaced one well to 10 acres. In many fields the practice has been to space them much closer than this; and in many town-lot developments, several wells have been drilled on an acre.

Slichter [c] demonstrates that in water wells in homogeneous formations, the total flow of two wells 200 feet apart is about 169 per cent

[a] Bowman, Isaiah, Well-drilling methods: U. S. Geol. Survey Water-Supply Paper 257, 1911, p. 51.

[b] Slichter, C. S., Theoretical investigation of the motion of ground waters: 19th Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, p. 367.

[c] Slichter, C. S., op. cit., p. 377.

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of the flow of a single well. If a third well be placed midway between the two, so as to make a row of three wells 100 feet apart, the total combined flow from the three wells is about 207 per cent of the flow of a single well. On the basis of relative viscosities of light crude oils and water, the same figure would apply approximately to oil wells 400 feet apart. This disregards differences in the porosity of the sand, varying gas pressures, etc. In a normally tight sand, wells may be drilled closer together in order to drain the territory at the same rate, the character of the sand preventing excessive refrigeration due to the free escape of the gas. In such a tight sand neighboring wells do not affect each other to the same degree as in a very porous stratum; that is, such pronounced drainage channels toward the wells first drilled are not formed.

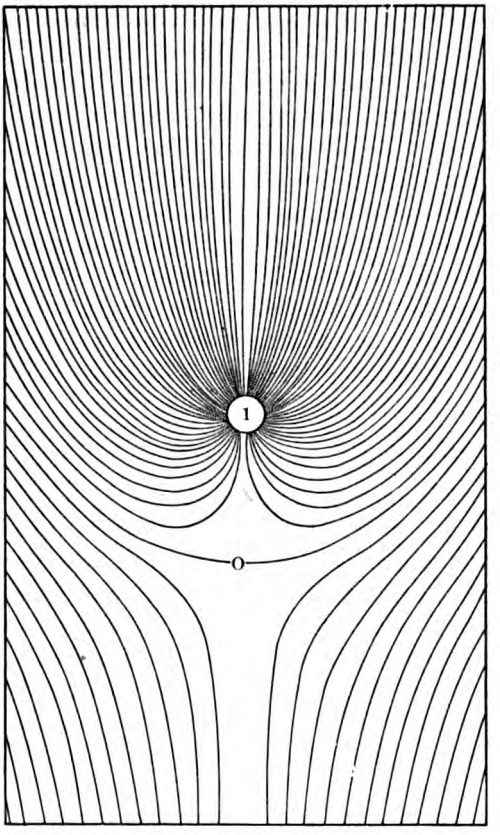

FIGURE 7.—Lines of flow into a well in a region where the water or oil has a constant motion in a general direction.

Figure 9, after Hager,[a] indicates how the first well (1 in the figure) drilled in loose unconsolidated formations, such as the Tertiary and Cretaceous sands of California and Louisiana, will set up drainage lines in all directions, so that later wells (2, 3, 4, and 5 in the figure) will produce little or nothing, although there are still large quantities of oil in the field. Well 1, however, continues to produce prolifically. Figure 8 shows the lines of flow for two interfering wells in the case where one well has double the capacity of the other, the larger presumably having been drilled first.

Town-lot development and the conditions brought about by many operators with small leases fighting for production result in extravagant and wasteful methods of production. Likewise, in the case of the Government leases in Oklahoma—the so-called "short-term"

[a] Hager, Dorsey, Geological factors in oil production: Min. and Sci. Press, vol. 103, Dec. 9, 1911, p. 740.

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leases—operators were led to drill uneconomically in order to extract the maximum amount of oil before the leases expired. Such development means uneconomical production throughout—drilling more wells than are necessary, pumping too fast, wasting gas pressure (and the gas itself), in flooding wells, and pumping one well against another, thereby creating underground conditions favorable for the encroachment of water.

To drain an oil property most efficiently, that is, to extract all the oil possible with a minimum number of wells and at an economical rate of production, it is essential to consider the best distance at which to space wells. This distance will of course differ for every producing stratum, and for every field.

In a great many fields the territory is divided among a number of operators, each working against the other to extract the most oil possible before his neighbor has a chance to take it. This usually results in the holders of small leases drilling as many wells as possible close to the boundary lines, forcing the lessees of surrounding land to drill well for well in order to protect their own property. As a matter of course, in such cases, no attention is paid to the proper spacing of wells, nor to the probable effect of one well on another. When large operators control sufficient acreage, the common practice in the older fields is to space wells from 400 to 500 feet apart.

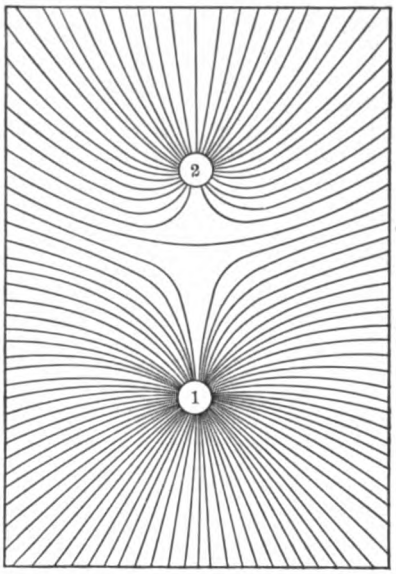

FIGURE 8.—Lines of flow into two interfering wells, one of which has double the capacity of the other.

As mentioned above, in some formations the first well drilled in a group will tend to set up drainage channels and divert large quantities of oil from a considerable area. Subsequent wells come in as much smaller producers than the original well. Again, in loose, unconsolidated sands, such as are found in the Caddo field in Louisiana, and in the famous Glenn pool in Oklahoma, if a well stops pumping for a day, the surrounding wells extend their own channels, breaking down the drainage system of the first well, to the extent that it is often difficult to again recover oil from the well that has stopped pumping. As a result the wells in the Glenn pool are pumped 24 hours a day, 365 days in a year. The condition of the sand in the Glenn pool was brought about somewhat artificially by the use of

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enormous quantities of nitroglycerin in shooting. The sand, originally coarse and porous, has probably been shattered throughout the entire producing area.

In certain lenticular formations, described by the oil man as "spotty," of two wells drilled only 150 feet apart, one has been a large producer and the other a dry hole. This discrepancy may be due to drainage conditions or may be caused by an intervening hard spot in the oil sand. If it is caused by drainage conditions the stopping

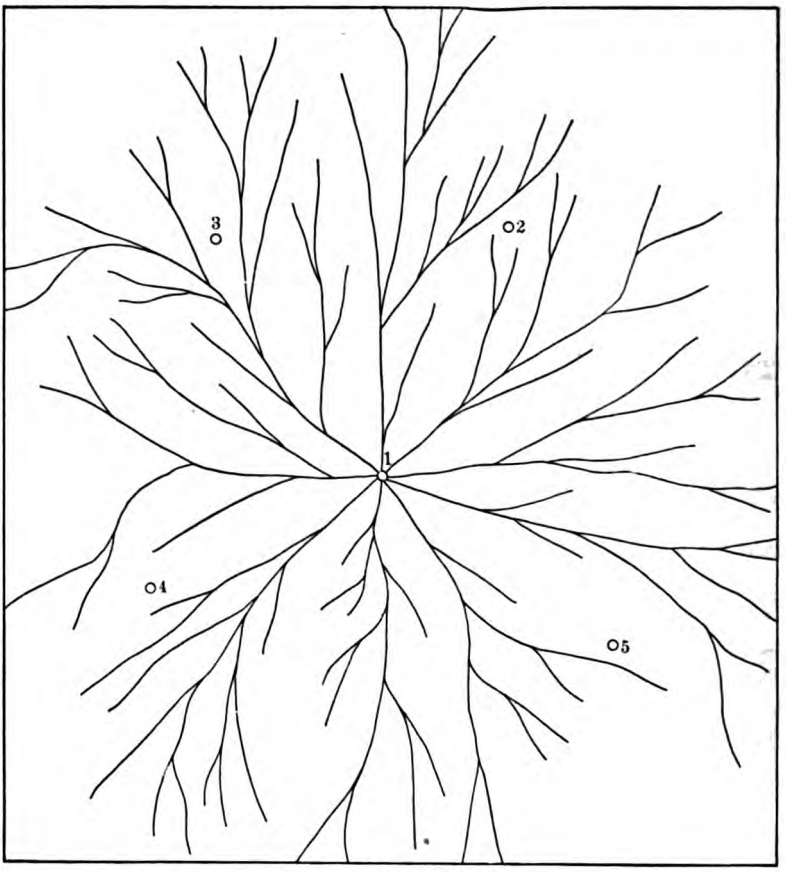

FIGURE 9.—Drainage lines of one well.

of the producing well would probably cause the other to produce. Again, wells 1,000 to 2,000 feet apart are in places so closely connected underground that the muddy water used in drilling one well has been pumped out by another well a considerable distance away, not necessarily the well nearest to the one being drilled. This condition is common in the Caddo field in Louisiana, and in other fields producing from the unconsolidated gravels and sands of the Cretaceous and Tertiary formations.

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In a previous paragraph is mentioned a case in the Vinton pool in Louisiana in which a well drilled near a good producer encountered a loose coarse pay sand. In the producer the sand was so loose that the rotary bit of its own weight immediately sank to the bottom. The second well struck sand, seemingly of the same nature, which immediately "packed," so that drilling was necessary to penetrate it. The second well never produced; moreover the sand "packed" in the original well, which likewise ceased to produce.

The Triumph pool in Pennsylvania was operated by means of gas pumps, so that there was a minus pressure of 10 to 12 ounces at each well.[a] It is possible that the Vinton pool, which is a small isolated pool in which all the wells drilled were producers at the time mentioned, was being operated under similar circumstances. There being no water to take the place of the oil extracted, when the second well was drilled, the sudden application of atmospheric pressure was sufficient to pack the sand and force the oil in the vicinity to other parts of the field where wells were being pumped. The oil is of a heavy asphalt base, with no gas content, and no water was encountered.

It is possible that the sudden flooding of some oil pools is occasioned by the drilling of a well into the water at a strategic point, thus putting an added pressure of 15 pounds per square inch behind the water, which perhaps lacked less than this amount of the force necessary to flood the oil-bearing district. Such a balance of forces would of course be rare and difficult to anticipate. Possibly a series of water wells drilled from time to time as the pressure in an oil pool diminished might reduce the rapidity of the flooding and yet be the direct means of flooding the oil-producing wells. However, practically the writer knows of no instance where such a procedure would have been warranted.

Again, the production of wells in pools producing heavy oils with little or no gas pressure, such as some small pools situated on quaquaversal domes along the Gulf coastal plain, might be increased by drilling air holes on the outskirts of the pools, thereby creating a draft from these points to the wells located in the center of production. If this should be done in pools situated in flat-lying strata or on very slight dips, the use of the gas pump to aid small wells might be avoided in some instances, the atmospheric pressure creating a flow of oil. This plan would at least be safer than an artificial flooding with water, if the underground conditions are practically unknown.

DECREASE DUE TO POOR MANAGEMENT.

Many wells cease to produce at an economical rate because of poor management of the numerous mechanical details. Some of these

[a] Carll, J. F., The geology of the oil and gas regions of Warren, Venango, Clarion, and Butler counties: Second Geol. Survey Pennsylvania, vol. III, 1880, p. 260.

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are enumerated below, but it may be said that it is in the surface management of wells that greatest improvement has taken place since the early days of petroleum production. In fact, it is remarkable to consider the great variety of time and labor saving contrivances now in use, as against the great dearth of information regarding underground conditions.

NEGLECTED CASING.

Casing corrodes more in some districts than in others. It is often allowed to deteriorate without attention until the result is the admission of water to the productive stratum from overlying formations or from the surface. This cause of decreasing production needs only the simple remedy of proper attention.

PUMPING METHODS AND REGULATIONS.

In most fields where producing wells are closely grouped as many of them as possible are pumped from a common power plant by "shackles" or "jerk lines." Some of the wells may be pumping from several different producing formations at the same time. Especially in the high-grade oil fields each well requires different handling, and the rate and the length of time for pumping most effective at one period of its life will not produce the best results at another. Although this variation is obviated to some extent by the use of "bleeders," "leaky valves," and other devices for automatically stopping the pumping of oil before the face of the sand is uncovered, yet such regulation is crude and leaves much to be desired. "Pumping by heads" is a step in the right direction, in that it conserves the gas pressure in the pool for the continued expulsion of oil and also tends to keep back salt water under pressure. However, under present practice it is impossible to judge the best possible time to pump and the proper height of oil column to leave in the well at all times. An automatic control, with valves set to start pumping upon the accumulation of a certain maximum pressure and to stop pumping upon the exhaustion of the oil to a certain set depth, would add greatly to the production in many cases, and would eliminate the possible negligence and usual lack of knowledge of the average pumper. Several automatic control devices are said to be on the market, and one at least has been tested with success. The problem of applying them is solely mechanical, and there can be little question as to the advisability of the use of such devices at a great many wells.

Incorrect pumping methods, by which a well is pumped too fast or too often or too deep, produce several bad results. The expansive force of the gas and its aid in the movement of the oil is lost by the gas being allowed to escape freely. Instead, only such an amount of gas as is associated with the head of oil pumped should be allowed to escape.

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The ideal cycle of production in a pumping well very closely approximates that of a well packed by the old seed-bag method, as follows (adapted from an unpublished manuscript by M. W. Quick):

(*a*) Pressure is developed in the well sufficient to overcome the resistance of the column of liquid in the tubing, which is expelled naturally or pumped off.

(*b*) The weight of petroleum in the well column overcomes the rock pressure and a point of equilibrium is reached. The excess of pressure of the shut-in gas over that of the column of oil has only a slight retarding effect on the further expulsion of oil, as the shut-in pressure can never exceed the rock pressure.

(*c*) The pump is started and the "head" of oil above the top of the sand is pumped off and the shut-in gas is allowed to escape. Thus the only gas released is that originally in the head of oil where it aids in expelling the oil.

(*d*) The well is again shut in and again heads.

Although such control is practically impossible where the pumping of a well is regulated by ordinary methods, yet an automatic device for such regulation would result in the maximum recovery of oil with the least possible loss of expulsive energy from the stratum. To duplicate this cycle, pumping methods must be controlled by intrastrata conditions in some automatic manner, otherwise wells will be pumped too frequently to insure the greatest production. The refrigerative resistance of chilled oil may not be overcome between the pumping of accumulated heads of oil, and energies for the expulsion of sediments and waxy accumulations may not be developed.

Automatic devices are on the market, but owing to the inertia of the producer relative to trying out such seemingly revolutionary schemes, they have not been given a fair trial under the conditions to which they are adapted. A general recognition of the need of such automatic control for the pumping of oil wells, governed by the natural underground conditions at each well, would result in the perfecting of many details to adapt the devices to the varying needs of different fields. Thus the production of districts now being abandoned with large quantities of oil still remaining in the rock would be increased. The requirements of each well vary and the necessities of to-day will not apply to-morrow. Conservation of rock temperature to prevent chilled and "cut" oil, by the use of head pumping, bleeders, or leaky valves, causing the flooding of the sand and reducing refrigeration of the gas by expansion, is necessary in the fields producing high-grade paraffin oil. It is not necessary in the Mexican and other fields producing heavy oils that contain no spontaneously volatile hydrocarbons. The rock temperature of the low-gravity oils of Texas, California, and Mexico is frequently higher than that of the surface, that of the Mexican oils being from 110°

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to 130° F. If this were not so, the high production of wells in these fields would be an impossibility. High-grade gaseous oil must of course be handled differently from the heavy oil of the fields last mentioned.

The flowing of wells by compressed air is falling into disuse in the eastern and Mid-Continent fields, as it has a tendency to cut the casing and the tubing. Flowing is not economical for small wells, there not being a sufficient head of oil against which the air may act. The effect in practice is to increase vaporization and the formation of waxy sediments and to clog the face of the sand.

Air-lift pumping has been tried with the same effects as regards increasing the chilling of the oil and the formation of paraffin.

CONSTRUCTION OF WELLS.

Increased production may sometimes be obtained by using large casing. This makes possible the use of large strainers where desirable, and the use of an inside perforated casing or liner where the formation is inclined to cave and cause the casing to collapse; in fact, the large-sized holes make the future handling of the well, or future deeper drilling, an easier problem. It may be said that wells that might flow naturally with a small-sized casing would cease to do so through a large hole. This difficulty is sometimes overcome by using a reducer on the bottom of the lowest string of casing, the well flowing through a 2-inch tubing for a long period after it has ceased to flow with only the $5\frac{3}{16}$-inch casing in the hole. The larger hole has a tendency to drain the territory more quickly, and consequently the well will very probably be shorter lived than if the hole were smaller in diameter. Also the larger hole probably results more frequently in chilled oil, caused by the greater surface from which volatilization occurs. Enough information has not been gathered to give definite figures as to this.

TAPPING ALL OVERLYING "PAY" STRATA.

In the early development of new fields, in the hurry to tap the principal oil stratum in advance of rival operators, all overlying "pays" are neglected and usually are cased off, no record of them being kept by the driller, who is usually paid for drilling by the foot or by the well. In later years, when production has fallen off in the older sand, it often becomes desirable to tap the upper sands, but by that time it is frequently impossible to know how deep they lie. In drilling by the wet method in the early days, the water pressure prevented some minor oil "pays" from indicating their presence. These have since been developed and some of them have proved large producers.

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DEEP DRILLING.

Improved methods of drilling, a better knowledge of the geology of oil and gas, and the rapidly increasing demand for petroleum have recently resulted in a search for petroleum by deep drilling in many of the older fields, some of which are enjoying a new lease of life, notably parts of the Clinton sand fields of eastern Ohio, the St. Mary's pool in West Virginia, and some of the Pennsylvania fields. It is considered not improbable that the Mid-Continent fields have a deep-sand future.

SPACING WELLS.

In spacing wells the utilization of the movement of the oil in a pool, and the thorough draining of the maximum amount of territory with the minimum number of wells are the two main considerations. As regards the first, as has been mentioned, the wells should be spaced closer together across the dip of the formations than down the dip, or in the direction in which the oil is draining. In any given field advantage should be taken of all available data bearing on the effects of wells on each other at different distances and in different directions. Hager[a] gives an interesting method for obtaining data regarding the proper number of wells necessary to drain a certain given territory, as follows:

The property, 640 acres, is underlain by three sands. The table below shows the known and the computed information prepared * * * from a study of a large number of wells.

Table A.

Area underlain by sands.	Thickness of sands under each acreage.	Number of acre-feet.	Computed quantity of oil available.
1	2	3	4
Acres.	*Feet.*		*Barrels.*
200	95	19,000	9,000,000
200	65	13,000	6,600,000
240	40	3,600	4,400,000
640		41,600	20,000,000

Table B.

Thickness of sands.	Production per thickness in 1.	Life per thickness in 1.	Number of acres.	Computed number of barrels available.	Number of wells needed.	Acres per well.
1	2	3	4	5	6	7
Feet.	*Barrels.*	*Years.*				
95	180,000	9	200	9,000,000	50	4
65	120,000	7	200	6,600,000	55	3.6
40	80,000	5	240	4,400,000	55	4.4
			640	20,000,000	160	[b] 4

[a] Hager, Dorsey, Geological factors in oil production: Min. and Sci. Press, vol. 103, Dec. 9, 1911, p. 739.
[b] Average.

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Columns 1, 4, and 5 are taken from table A and correspond to columns 1, 2, and 4, respectively, (which are of importance in reaching a conclusion as to the number of wells needed). Columns 2 and 3 in table B are derived from data collected from a study of a large number of wells. Column 4 is obtained by dividing the figures in column 5 by those in column 2. Column 7 is obtained by dividing the figures in column 4 by those in column 6. These results are purely assumptive, and should in no way be considered as of value except for the purpose of illustration.

As Hager states, "Every operator desires some idea of the amount of oil he may reasonably expect from a property. Estimates of this kind are only approximate and are useful guides to conservative men." The above method should be used with care and in connection with all data obtainable as to the location of the property in relation to the rest of the pool, and in estimating the theoretical quantity of oil available from the thickness of the sand, good judgment based on accurate data is necessary to determine the true thickness of the sand as shown by the drillers' logs. In some pools only a part of the porous stratum is saturated with oil, or other prevailing conditions make calculation of the oil content on this basis incorrect. The method could, of course, be used only in territory already proved.

CLEANING WELLS.

With regard to cleaning wells, Roswell Johnson, professor of petroleum engineering, University of Pittsburgh, makes the following statement [a] regarding the Mid-Continent fields:

I find that there are operators who never clean their wells, others who do so only as a last resort when the well is near abandonment, and others who do it periodically. I should say that on an average wells are not cleaned oftener than once in three years. This matter is important, because the practice is so variable, and the work is so expensive. My own views are as follows:

METHODS OF CLEANING UNDER DIFFERENT CONDITIONS.

Where water is not found in the sand.—In case the sand does not carry water a pocket about 10 feet [b] deep should be drilled below the sand. Besides the possibility of revealing a second pay the pocket provides a receptacle for loose sand or cavings without affecting the well. I would have the intake of the pump opposite the bottom of the pay and have a small air hole in the working barrel near its top at the top of the pay. The first cleaning immediately after the shot should be thorough and should empty the pocket. Such a well, by sanding its pump cups, will automatically show when cleaning is needed. When the pump is pulled for renewing the cups the depth of the well should be measured with a tape to see how much the pocket has filled. If the filling is more than 2 feet, it probably will pay to clean the pocket; if the filling is less, the working barrel can be set higher until the cups have to be replaced again. Of course, with oil selling at 60 cents one would not be as intent on cleaning as with oil at $1.50. As soon as a well is in good shape I think the derrick should be removed and used elsewhere. Pulling is done with a pulling machine and cleaning with a drilling machine. I think the shot should be placed at the bottom of the pay, so that the hole made will extend still farther and, with the pocket, give space for a considerable accumulation of loose sand before the intake is reached. When the well

[a] In a letter to the author.

[b] In the Ontario peninsula pockets 50 to 100 feet deep are drilled by the leading operators.

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becomes unremunerative a working barrel without the air hole may be put in; then the well can probably be pumped a little while longer.

Where there is nonencroaching water under low pressure in the bottom of the sand.—If there is water under low pressure in the bottom of the sand, drilling should be continued until water is evident, and should not be stopped at the depth where water is expected. The pocket should be omitted and the well should be shot at a point only 1 foot above the supposed line between the water and the oil. The first cleaning should be thorough. Effort should be made to have the well "make" considerable water with the oil, care being taken, of course, not to get so much that a 24-hour flow through the 3-inch pipe will exhaust the water, if fuel is cheap. By taking this water, assurance is had that no pay will be missed; also the current of the water flowing to the hole helps to move in the oil.

Where there is nonencroaching water under high pressure.—In case there is nonencroaching water under high pressure, care should be taken to stop wells a little short of the water. They may be drilled deeper to the water when it is desired to clean them. In my opinion, many of our deserted wells could, if containing water, have been handled a year or two later when neighboring wells had reduced the pressure.

Where there is encroaching water.—If there is encroaching water, wells must stop a little short of the water; hence the shot should not extend to the bottom.

GENERAL METHODS OF CLEANING.

The methods of cleaning in general use may be enumerated as follows:

1. Removal of accumulated sand by tools and sand pump.
2. Hot-billet treatment. I am not familiar with the results of this method, which is probably most useful where the oil carries a high percentage of paraffin.
3. Gasoline treatment. I believe this method preferable to the hot-billet treatment, and very useful where the refinery owns the well and can thus recover the gasoline.
4. Freshening the hole with a small torpedo. This expedient is not necessary when the sand runs in freely. It is probably most useful where some kinds of water are associated with the oil or the oil is asphaltic.

In regard to freshening the hole with small shots, so-called "squibbing," it may be said that the effect is probably to furnish the heat necessary to redissolve the accumulated waxy paraffins that clog the hole and to cause their expulsion by fresh oil. Even though it be conceded that close argillaceous and calcitic sandstones saturated with petroleum require shattering, the conclusion does not follow that all sandstones should be treated with large quantities of high explosives, as shooting often produces a heating rather than a shattering effect. In a hole full of water the liquid takes up the shock of the shot and prevents shattering, yet the shooting results in increased production by causing a fluxing of the waxy sediments.

In other wells "pay" streaks are unknown, but shooting in later years may start them flowing.

CONCLUSION.

The present paper is intended merely as a brief preliminary outline of certain aspects of the technology of the oil industry that will be taken up more in detail in later papers. The spacing of wells, the construction and management of wells, the encroachment of water, the conservation of gas, the cleaning and pumping of wells, are all subjects demanding the closest attention and the most detailed study

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at this time, for the reason that the life of the industry depends on the lessening of waste and the proper exploitation of our petroleum resources. Technical Paper 38 [a] of the Bureau of Mines discusses ways and means for the conservation of natural gas in the United States.

Exact information regarding the yield of wells is meager and unclassified, so that the preparation of a report on the technology of this important branch involves not so much compilation of published data, but rather, to a large extent, the recording of results of extended inquiries in the field. The persons consulted frequently have no conception of the relation of the information they give to the problems under consideration. On the other hand, many producers and operators are improving their methods as a result of experience, realizing that the problems in new fields or new pools can not be handled by rule-of-thumb methods. Such methods, although excellent for the conditions under which they originated, can not always be applied to conditions in new fields and to drilling and operating under unforeseen difficulties.

PUBLICATIONS ON PETROLEUM TECHNOLOGY.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 19. Physical and chemical properties of the petroleums of the San Joaquin Valley, Cal., by I. C. Allen and W. A. Jacobs, with a chapter on analyses of natural gas from the southern California oil fields, by G. A. Burrell. 1911. 60 pp., 2 pls., 10 figs.

BULLETIN 65. Oil and gas wells through workable coal beds; papers and discussions by G. S. Rice, O. P. Hood, and others. 1913. 101 pp., 1 pl., 11 figs.

TECHNICAL PAPER 3. Specifications for the purchase of fuel oil for the Government, with directions for sampling oil and natural gas, by I. C. Allen. 1911. 13 pp.

TECHNICAL PAPER 10. Liquefied products from natural gas; their properties and uses, by I. C. Allen and G. A. Burrell. 1912. 23 pp.

TECHNICAL PAPER 25. Methods for the determination of water in petroleum and its products, by I. C. Allen and W. A. Jacobs. 1912. 13 pp., 2 figs.

TECHNICAL PAPER 26. Methods of determining the sulphur content of fuels, especially petroleum products, by I. C. Allen and I. W. Robertson. 1912. 13 pp., 1 fig.

TECHNICAL PAPER 32. The cementing process of excluding water from oil wells as practiced in California, by Ralph Arnold and V. R. Garfias. 1913. 12 pp., 1 fig.

TECHNICAL PAPER 36. The preparation of specifications for petroleum products, by I. C. Allen. 1913. 12 pp.

TECHNICAL PAPER 37. Heavy oil as fuel for internal-combustion engines, by I. C. Allen. 1913. 36 pp.

TECHNICAL PAPER 38. Wastes in the production and utilization of natural gas and means for their prevention, by Ralph Arnold and F. G. Clapp. 1913. 29 pp.

TECHNICAL PAPER 42. The prevention of waste of oil and gas from flowing wells in California, with a discussion of special methods used by J. A. Pollard, by Ralph Arnold and V. R. Garfias. 1913. 15 pp., 2 pls., 4 figs.

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[a] Arnold, Ralph, and Clapp, F. G., Wastes in the production and utilization of natural gas and means for their prevention.

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